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Evaluation of Hides, Wet Blue and Leather Using Airborne Ultrasonics

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by

Cheng-Kung Liu,*[1] Nicholas P. Latona[1] and Seung-Chul Yoon[2]
*United States Department of Agriculture,***
Agricultural Research Service

[1]*Eastern Regional Research Center,*
600 East Mermaid Lane, Wyndmoor, PA 19038

[2]*Russell Research Center,*
950 College Station Road, Athens, GA 30605, USA

Abstract

Animal hides are important agricultural commodities closely associated with rural economics and the well being of rural farmers in the United States. Approximately 90% of the hides produced in the United States are being exported; the remaining 10% are mostly tanned into leather. At the present time hides and leather are visually inspected and ranked for quality, usable area, and sale price. However, visual inspection is not reliable for detecting defects, which are usually hidden inside the material or under the hair in fresh hides. This manual assessment is not uniform among operators, and often leads to disputes over fair price. Development of a non-contact nondestructive method to accurately evaluate the quality of hides and leather is urgently needed. We previously reported the research results for airborne ultrasonic (AU) testing using non-contact transducers to evaluate the quality of hides and leather. We demonstrated the ability of AU to reveal defects in hides and leather that are difficult to be found during visual inspection. In this paper, we present new results on AU inspection, particularly using a statistical data/cluster analysis technique, in which leather and hide defects are depicted as color-coded amplitude maps, or "C-scans."

Introduction

Animal hides are visually inspected and ranked for quality, usable area, and sale price. Because visual inspection is not reliable for detecting defects when hair is present, hides cannot be effectively sorted at the earliest stage of processing. Furthermore, this subjective assessment is not uniform among operators, and leads to disputes over fair price.[1] Therefore, the development of an objective and nondestructive method to accurately evaluate the quality of hides is needed. Airborne Ultrasonic (AU) methods have been used extensively in the inspection of lumbers and composites.[2,3] In previous research, we demonstrated that AU testing without direct contact with samples offers a great potential method for the nondestructive evaluation of the material properties of leather.[4,5] AU testing involves pulsing ultrasonic signals at the material and measuring the reflected or penetrated amplitude of those signals emanating from the material.[6] The amplitude of ultrasonic signals transmitted through the samples is known to be a function of the tested material's properties and quality.[6] Our previous studies indicated that AU testing can reveal the presence of defects in the leather or any other physical discontinuity that could affect the leather quality.[4] AU waves must travel from a medium with low acoustic impedance (air) to a medium with considerably higher acoustic impedance (leather), therefore selection of the proper AU transducers and frequency are critical to achieve enough penetration of ultrasonic waves in order to extract important information related to the structure and properties of leather, such as the amount of defects, morphology, strength and softness.[4]

*Corresponding author e-mail address: ChengKung.Liu@ars.usda.gov; Tel (215) 836-6924

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In this study, AU testing involves pulsing ultrasonic waves and measuring the amplitude of those waves transmitted through the material; we believe by using the through transmission mode, more useful information can be extracted from the AU scan, particularly for hides, which are covered by hair. The major challenges to effectively determine the defects within or on the hides, will be to identify the right transducers, frequency, and scanning speed as well as establishing a correlation between the quality of hides (related to integrity and defects) and the corresponding AU quantities. The variations in the AU quantities, such as amplitude or time of flight (TOF) are colored coded into C-scan images to reveal the location and shape of the defects or some other physical discontinuity that could affect the hides or leather quality. In an earlier report, we demonstrated that the airborne C-scan imaging technique can be used to reveal the presence of areas of different acoustic properties that are an indication of local variations of the material properties of hides or leather.[5] Transmission of the ultrasonic waves correlates with the modulus of elasticity as seen in the milled vs. non-milled crust leather.[5] Softer materials usually have a higher acoustic impedance than stiffer materials. We observed that the amplitude of the ultrasonic reflected signal is related to the stiffness of the leather because it is closely related to the elasticity of a material.[5] The velocity of the sound through a material (v) is proportional to $(E_{xy}/\rho)^{0.5}$, where (E_{xy}) is the elastic constant and (ρ) is the density. Since leather and hides are anisotropic in nature the elastic constant, E_{xy}, could depend on which direction to the backbone the elastic modulus is measured. Other important factors are voids, moisture content, and frequency. This AU imaging technique revealed the presence of defects in the hides created by healed wounds and other physical discontinuities that could affect the leather quality. Additional work has been done since our last report; here we will present additional new findings, particularly about research results on using software to translate the C-scan of a hide into numeric values that reflect the extent of defects and integrity of hides, which can then be used as a more objective grading system.

EXPERIMENTAL

The schematic illustration of the airborne ultrasonic experimental setup is shown in Figure 1. The system consisted of two ultrasonic transducers approximately 3 cm apart, a transmitter (model: NCG200-D50, The Ultran Group, State College, PA) with a 50 mm active area pulsed with a tone burst through a power amplifier, and a receiver (model: NCG200-D25) with a 25 mm active area connected to a preamplifier were mounted on a computer-controlled X-Y scanner using the software UTWIN version E1.81 (NDT Automation, Princeton Jct., NJ) that allows the transducer array to be moved over the entire surface of the hide. The samples were clamped taught across a frame with two parallel bars in order to minimize any slack in the sample. A test frequency of 200 KHz (having a wavelength in air of 6.35 mm) was chosen because it was low enough so ultrasonic attenuation (scatter and absorption) is greatly reduced to levels which permit ultrasound to readily propagate through both air and the samples of hides and leather targeted for inspection, yet high enough so satisfactorily small-diameter, well-collimated ultrasonic beams can be generated by acceptably small-sized probes (transducers). The transmitting transducers emit pulsed ultrasonic energy in the form of rapidly reoccurring tone bursts (cycle packets at the 200 KHz test frequency), which possess the necessary duration (pulse length) and amplitude to deliver the desired penetration power, yet minimize standing wave interference.

Figure 2 illustrates the transmission mode versus the different wave trains in the waveform generated during the pulsing of ultrasonic waves.[6] Figure 2a demonstrates the through or direct transmission of the waveform through the material and is represented in the A-scan (bottom of Figure 2) as gate 1. Figure 2b shows the thickness reflections of the waveform bouncing through the sample and finally to the receiver and is detected by gate 2. Figure 2c shows other reflections of the waveform caused by either the transmitter or receiver side reflections, which have no value in our current study. The

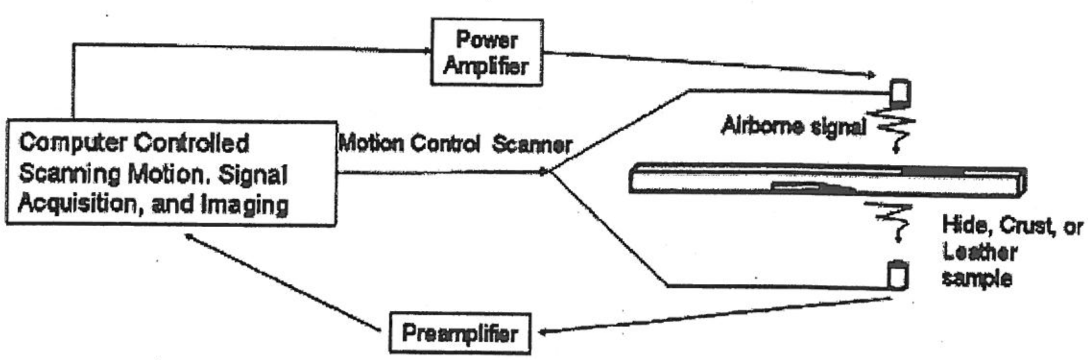

Figure 1. Schematic of airborne ultrasonic setup.

amplitudes of the transmitted airborne signals at every point on the hide surface were measured, color-coded, and mapped into an image file for each hide or leather. These color-coded amplitude maps are called "C-scans" and they are commonly used in the field of ultrasonics. The resolution of the C-scans generated was set to 0.5 mm in both the scanning and indexing directions. The scanning direction is the direction the transmitter is actively scanning the sample and the indexing direction is the stepping direction to move the transmitters up to the next position for scanning. The color-coding of the C-scans is set up in the UTWIN software and is determined from the root mean square voltage (V_{rms}) of the receiver between two set time gates (t_1 and t_2), as seen in Figure 2, for every spatial point measured on the sample and is referred from this point on as the amplitude.[7] The gain was set at 15.5 dB out of a maximum of 36.5 dB, unless otherwise noted.

Converting the C-scan images into numeric data is the key step to enable one to quantitatively represent the defective regions in hides or leather. Clusters with similar amplitudes were analyzed to identify regions of interest and quantitatively asses the C-scan data. Two amplitude threshold regions of interest selected were 20 to 50%[4] and 80 to 100%. It was demonstrated previously that the 20 to 50% amplitude range correlated with Nissan Shirley stiffness values, but not any of the other mechanical property values.[4] The minimum cluster size was set at 0.5 mm^2 or 2 pixels in which groups of pixels 0.5mm^2 or 2 pixels or bigger is considered a cluster. The cluster neighborhood was set to 2.5 mm or 5 pixels, which indicates the minimum distance between the closest edge points in a cluster or group or pixels. If two clusters are closer than the set distance of 5 pixels, (set cluster neighborhood value) they are considered to be one cluster. The total area of all the clusters in the set amplitude threshold is calculated and represented as the percent area within the defined amplitude threshold.

Mechanical properties were tested on 5- x 0.5-cm rectangular samples cut out from split grain, split corium crust and vertical fiber crust leather. Testworks-4 data acquisition software and an Insight 5 materials tester (MTS Systems Corp., Minneapolis, MN) were used throughout this work. The grain and corium crust were measured with a sample length of 2.5 cm between the two grips and the vertical fiber defect samples were measured with a grip distance of 5 cm. The strain rate (crosshead speed) was set at 25.4 cm/min. All samples were tested in a conditioned room set at 23 ± 2 °C and 50 ± 5% RH.

RESULTS AND DISCUSSION

The velocity, amplitude, and duration of ultrasonic waves measured by the receiver changed with the material properties of test samples. For one AU scanning result, there are various AU quantities that can be displayed as a function of time or sample position. Figure 3a shows two C-scans taken at different gates along the waveform (A-scan) shown in Figure 3b. The C-scan is very commonly used in AU testing, in which the transmitted AU pulses were captured and the amplitudes

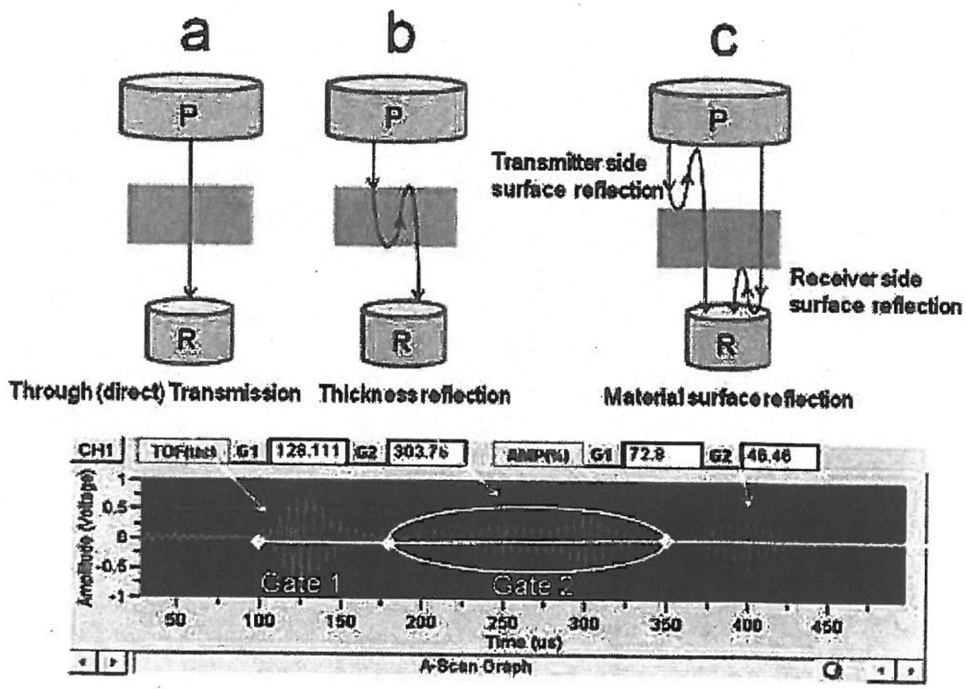

Figure 2. Transmission mode (a) through transmission, (b) thickness reflection, and (c) material surface reflection vs. wave trains (a) Gate 1, (b) Gate 2, and (c) remaining waveforms.[6]

of the transmitted pulses were mapped using pseudo color from the maximum amplitude in gate 1 or gate 2 set on the A-scan (Figure 3b). The color map shown in the figure is proportional to the amplitude of the signal with dark brown being the highest amplitude and deep blue being the lowest. This method is commonly applied to airborne ultrasonics. Figure 3b shows a so-called "A-scan graph," in which the amplitude of the received pulse is represented along the y-axis and the travel time of the ultrasonic pulse is represented along the x-axis. The C-scan images in Figure 3a are similar, however each C-scan is mapped from a different gate on the A-scan, where it was determined that the first large peak of the waveform in Figure 3b, named gate 1, varied the most with the different hide and leather samples tested, therefore the C-scans were based on gate 1. This is because the gate 1 signals come directly from the transmitted waves without reflections as shown in Figure 2. As shown in Figure 3's C-scans for a wet blue sample, the C-scan from gate 1 seems to provide more information about the distribution of the amplitude.

Further information can be obtained and used to interpret C-scans, such as in Figure 4a, which is a C-scan image of wet-blue with a brand of the letter "A." From the horizontal line of the crosshair displayed in Figure 4a, one can see the topography of the wet blue scanned and there is some variation of the surface seen by the two higher vertical regions, one in yellow and one in red, which represent the upper part of a brand embossed on a cow in the shape of an A. Figure 4b demonstrates a b-scan, which graphs the data horizontally. The featured data along the horizontal line are represented by a bar plot in which the y-axis is the peak amplitude of the waveform in gate 1 and the x-axis represents the transducer displacement. The B-scan image, Figure 4c, which graphs the waveform vertically, is determined by the entire A-scan regardless of where the gates are and demonstrates the TOF soundpath through the material in order to calculate the thickness or depth based on the wave velocity. Each line on the image corresponds to an individual peak or reflection on the waveform at a data collection point. The travel time of an ultrasonic pulse is represented as a displacement along the y-axis, and transducer movement is represented as a displacement along the x-axis. The two horizontal lines in Figure 4c between approximately 100 and 200 μs represent the brand in the wet blue sample and horizontal lines after 200 μs are the multiple reflections of the waveform in the wet blue.

A study was performed in which a raw steer hide was processed into the crust leather and scanned using the same approximate area at the raw stage with hair on, wet blue full thickness, wet blue split grain and corium layers, and the crust grain and corium layers seen in Figure 5. As demonstrated from the raw hide image in Figure 5, the raw hide does not show a uniform C-scan. The blue areas present low amplitudes while the green areas present medium amplitudes, and red areas are regions where there is a large signal transmitted as indicated on the color bar scale. After processing into wet

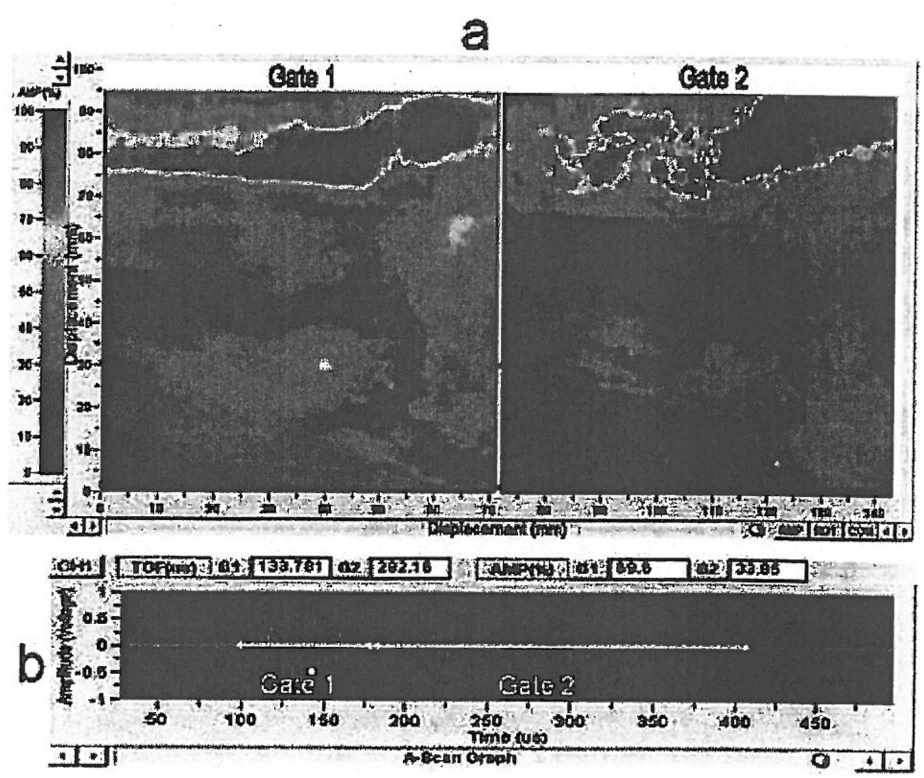

Figure 3. A typical (a) C-scan image and (b) A-scan graph in AU test.

blue, there is a completely different C-scan from the raw hide, and further processing the wet blue by splitting and converting the different layers into crust shows these processing steps affect the structure of the material. The high amplitude areas on both sides of the grain and crust leather in Figure 5 represent air and were scanned on the outer edge of the sample due to the shrinkage of the crust leather. The grain and corium crust C-scans shown in Figure 5 are very similar and the average mechanical properties are very similar as well. The results of Figure 5 indicate each step of the leathermaking process, the resultant fibrous structure becomes more solidified and dense, which results in less penetration of the ultrasonic waves. The average tensile strength for the grain crust was 12.6 ± 2.3 MPa versus 13.6 ± 3.6 MPa for the corium crust leather and the grain crust leather was thinner, 2.6 ± 0.4 mm versus the corium which was 3.5 ± 0.3 mm as seen in Table I.

It is interesting to compare the same area of raw hides and wet blue, as seen in Figure 6, one can see that the wet blue attenuates a lot of the ultrasonic waves (Figure 6a). This is ascribable to the denser structure of wet blue, which consists almost exclusively of collagen fibers, whereas hides have a significant portion of non-collagenous materials such as fat. This may also be due to differences in this particular hide as well. It has been observed that wet blue C-scans will vary depending on the hide, in that different hides will have different attenuations as well. The interesting thing about Figure 6 is in the Time of Flight (TOF) data, which is seen in Figure 6b, in which there is some resemblance of a circular pattern in the raw hide and wet blue. TOF is the travel time (μs) of sound waves through the test sample. It is reversely proportional to the velocity of sound. It reflects how "smooth" the sound can transmit through the sample, which should be

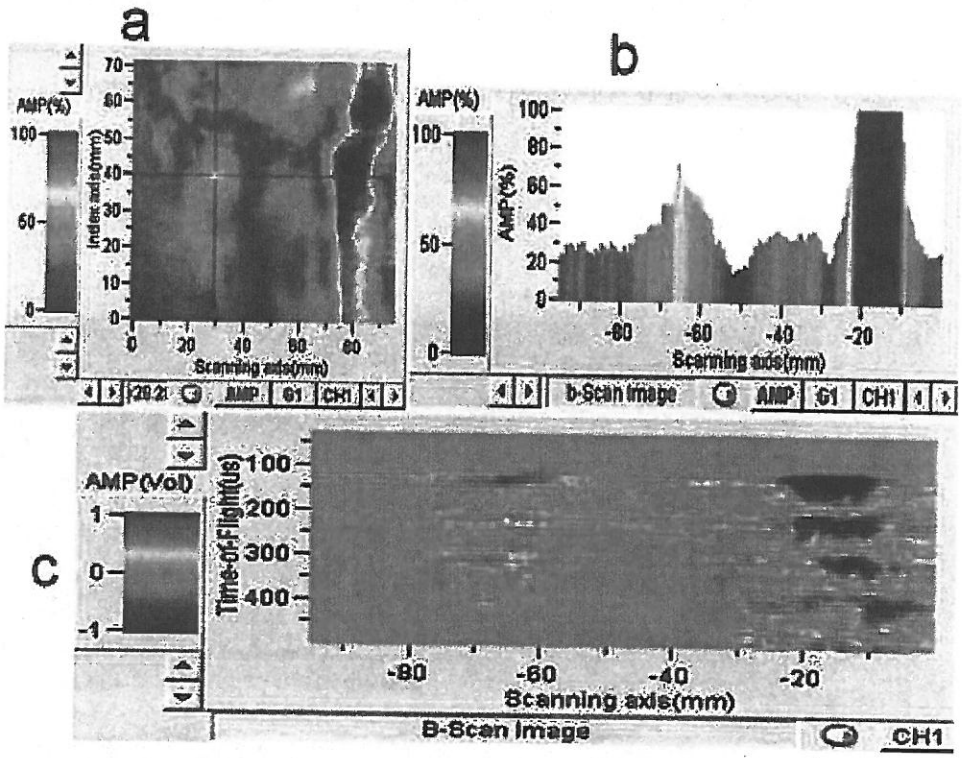

Figure 4. Examples of (a) C-scan, (b) b-scan and (c) B-scan images in AU test for wet blue.

TABLE I
Mechanical properties of grain and crust leather.

	Thickness (mm)	Tensile Stress (MPa)	Elongation (%)	Young's Modulus (MPa)	Fracture Energy (J/cm³)
Grain	2.6 ± 0.4	12.6 ± 2.3	36.3 ± 6.1	48.2 ± 15.4	2.6 ± 0.5
Corium	3.5 ± 0.3	13.6 ± 3.2	45.7 ± 10.2	47.5 ± 20.2	3.4 ± 0.8

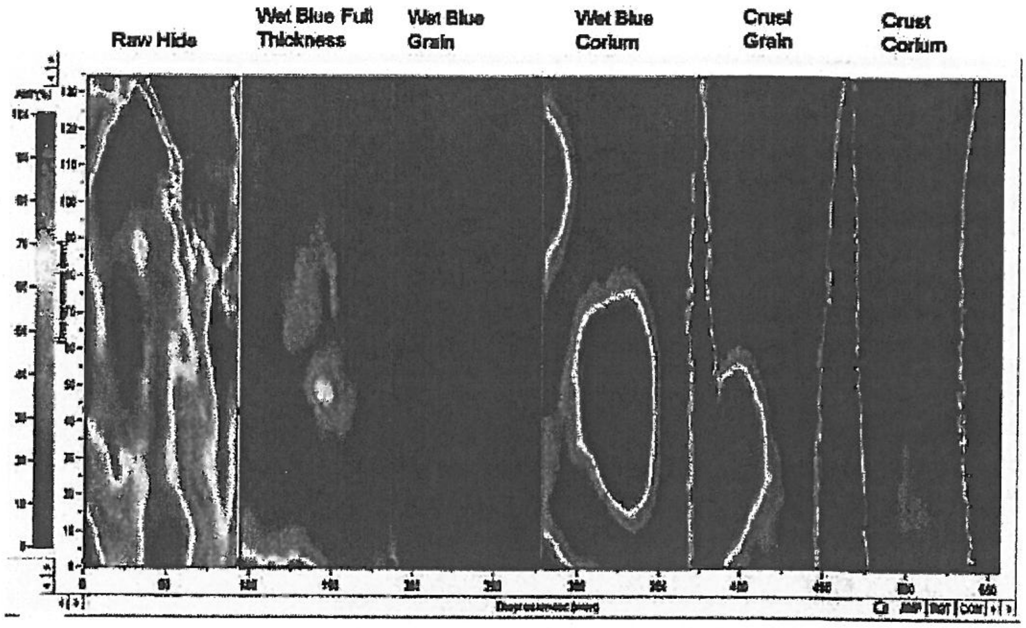

Figure 5. C-scans from the same piece of raw hide processed to crust leather.

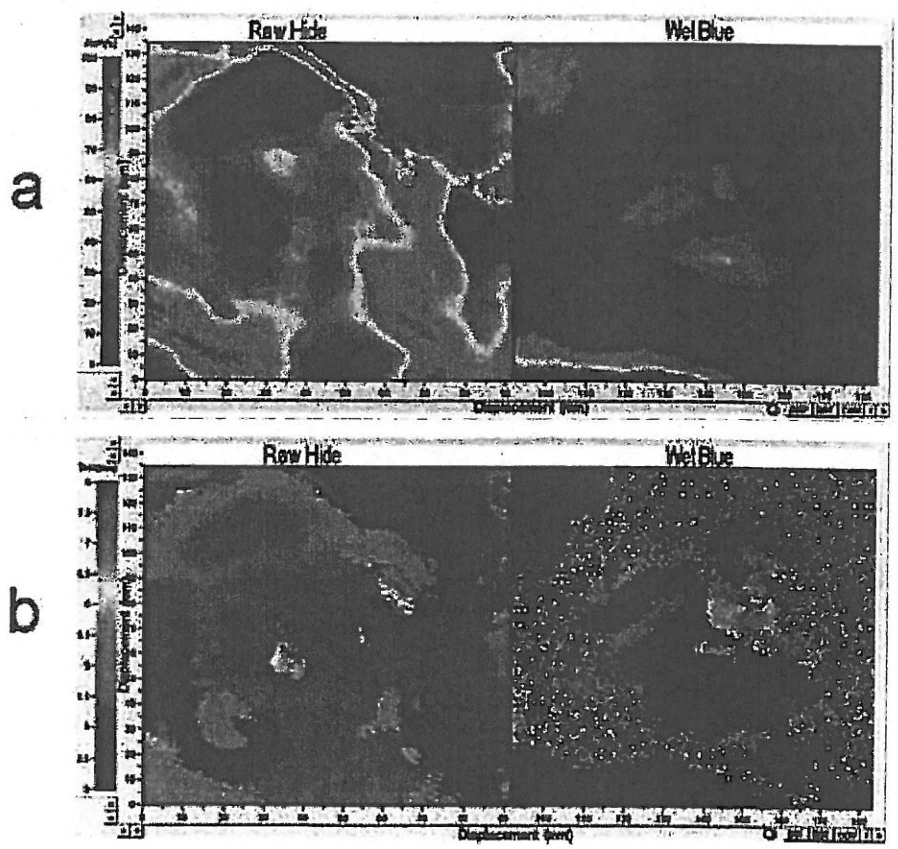

Figure 6. Differences in (a) Amplitude and (b) Time of Flight (TOF) for raw hide and corresponding full thickness wet blue.

governed by the property of materials. In future studies, the TOF data may become more important and might carry over better from the raw hide to the crust leather.

Further studies were performed to study the correlation and detection of defects between the raw hide and wet blue, since it is in the wet blue state where any grain defects can first be observed. Figure 7 demonstrates another C-scan of a fresh hide (Figure 7a) with the hair on versus the same corresponding area of the full thickness wet blue (Figure 7b), with a gain of 5dB, and a digital image of the approximate area scanned on the wet blue (Figure 7c). The cluster analysis was performed on the fresh hide and the wet blue, results showed there was an increase in the percent area between 80 to 100% amplitude for the raw hide (0.28%) versus the wet blue (9.78%) and a decrease in the 20 to 50% amplitude for the raw hide (73.64%) versus the wet blue (58.62%). If we look Figure 4b and corresponding digital image in Figure 4c, we can see two warts in the wet blue which may correspond to the lower dark red circle on the lower right and a yellow area up and to the left of the lower wart.

In Figure 8, it is seen just how important the sensitivity of the system can be as well as the difference in wet blue, which also

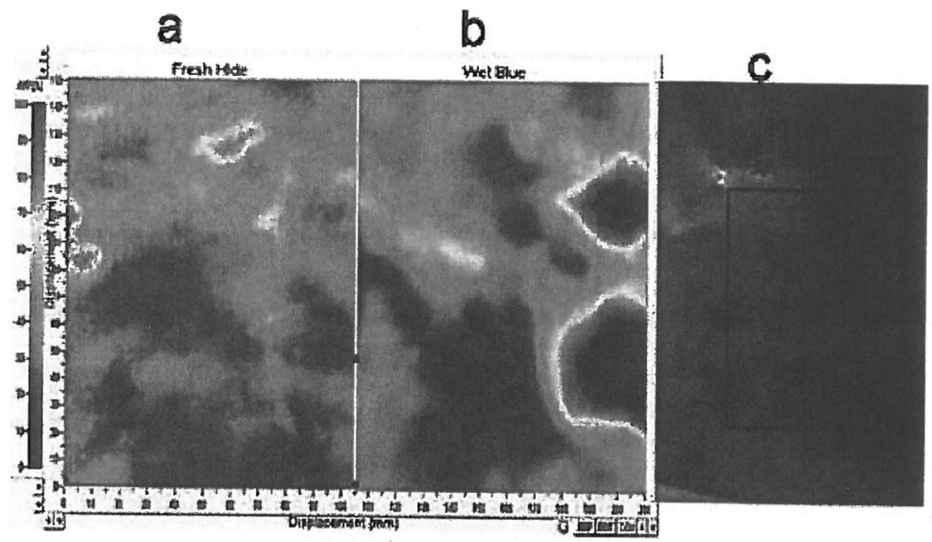

Figure 7. (a) C-scan images of hide with defects and (b) corresponding wet blue and (c) the photo of wet blue.

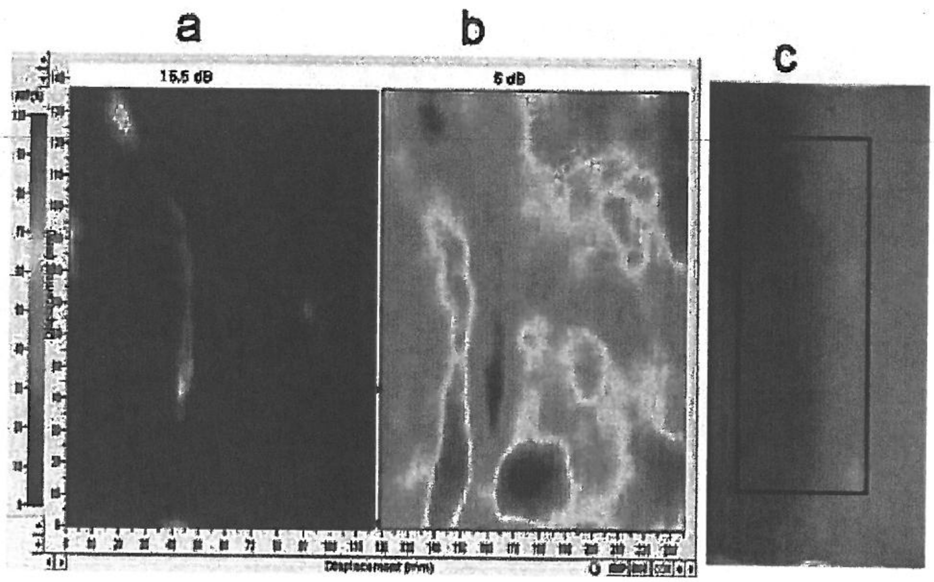

Figure 8. (a) C-scans from 15.5 dB gain, (b) 5dB gain, and (c) photo of wet blue.

may be due to the slight variation in each particular steer or cow. Figure 8 shows a wet blue hide that showed almost full penetration at 15.5 dB (Figure 8a) and needed to be decreased to 5 dB (Figure 8b), in order to extract any information out of this particular sample. From Table II, there is a huge drop in the percent area between 80 to 100% and 20 to 50% amplitudes. However, after decreasing the gain to 5dB for these two samples the percent area for the 80 to 100% amplitude range was very similar in that shown for Figure 7 (9.78%) and for Figure 8 (8.59%). The vertical line located at the x-displacements of approximately 40 mm and 160 mm for Figures a and b respectively may correlate to the crease caused from the wet blue being folded in the small sample drum when tanning.

Shaved (1.8-2.0 mm) commercial wet blue was obtained with a brand as demonstrated in Figure 9a. We observed as seen in Figure 9b, that multiple scans in one day without rewetting the wet blue resulted in a change in the amplitude of the C-scan images. The changes shown in Figure 9b is probably due the decrease in moisture content of the wet blue as the samples were left out in the open air. It was also observed in this wet blue that the sensitivity was also important, in that the usual 15.5 dB gain did not work very well and the gain had to be increased to 30 dB in order to acquire a good C-scan.

A further study was performed to measure the moisture content in wet blue versus the C-scan images, which is displayed in Figure 10. As shown in Figure 11, it is observed that the percent amplitude from 80 to 100% increased as the moisture content decreased. The percent area between 20 to 50% amplitude did not show as clear of a trend as the 80 to 100% amplitude (noted as AU%).

After splitting and shaving the wet blue, the average wet blue moisture content is usually between 50 to 54 percent. A C-scan image of shaved wet blue scanned at 51% moisture is demonstrated in Figure 12. Therefore at this moisture content, good C-scans are able to be obtained.

TABLE II
Gain difference versus percentage of area in amplitudes.

Figure 7 wet blue gain difference	Percent Area between 80-100% AMP	# Clusters	Percent Area between 20-50% AMP	# Clusters
15.5dB	98.78	1	0	0
5dB	8.59	6	25.01	7

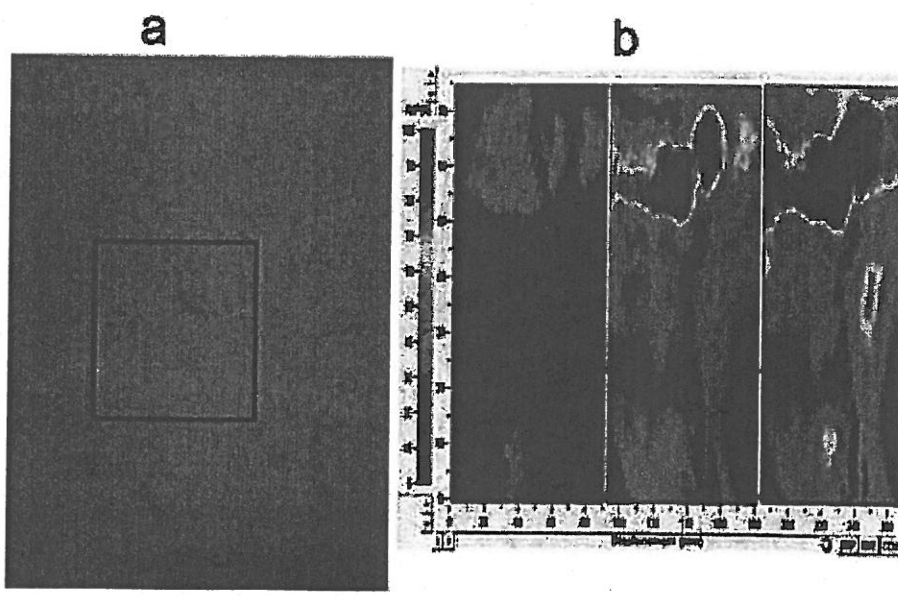

Figure 9. (a) Photo of wet blue with brand (b) corresponding C-scan with different time.

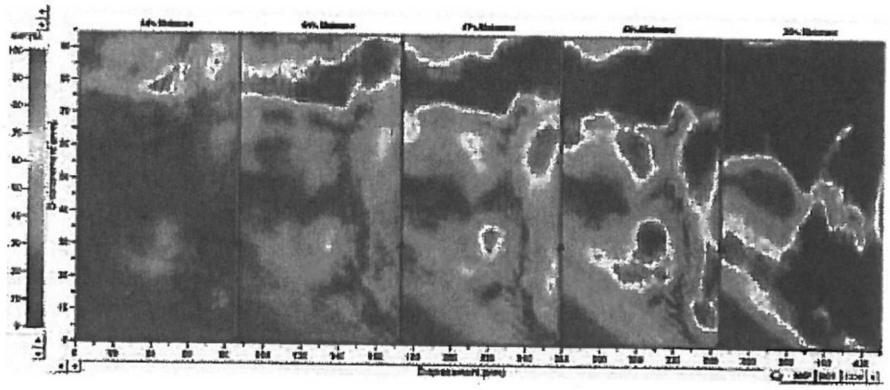

Figure 10. C-scan images of wet blue with brand at decreasing moisture levels: 61, 51, 47, 43, and 28%.

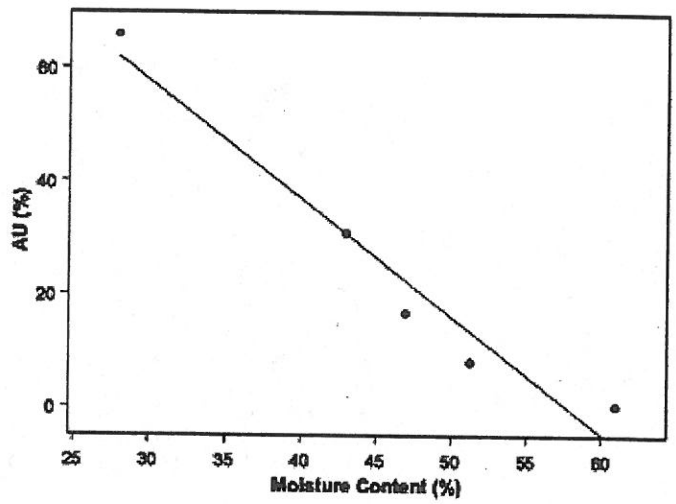

Figure 11. The relationship between percent area in 80-100% Amplitude range (AU%) and moisture content of wet blue.

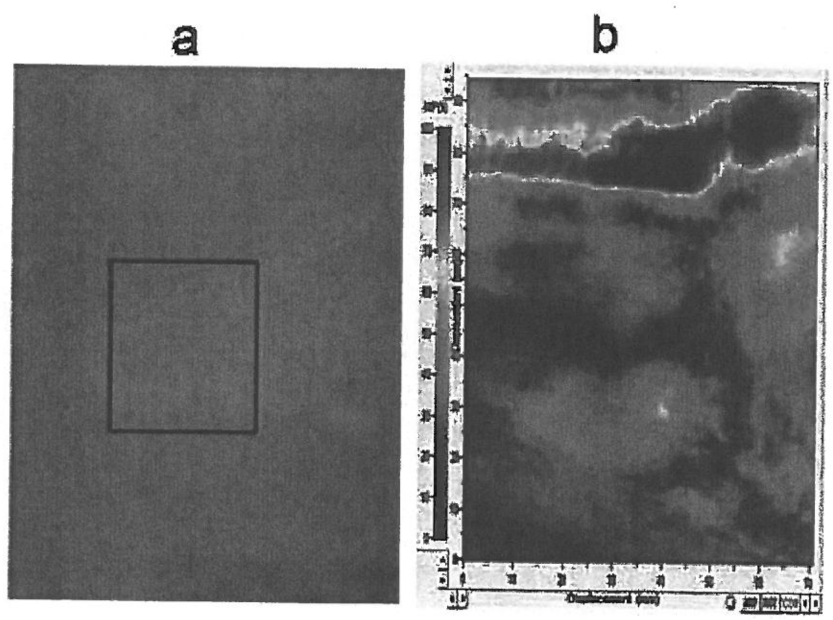

Figure 12. (a) Photo and (b) C-scan image of wet blue with brand at 51% moisture levels.

Vertical-fiber defect (VFD) is an abnormal arrangement of collagen fibers in hides of certain cattle breeds.[8] The vertical fibers occur only in the upper reticular dermis, with the fibers in the lower reticular dermis lying parallel to the plane of the hide in all phenotypes. VFD often results in 50% loss in tensile strength compared to the non-infected area. This defect is difficult to detect in hides until it was made into leather showing poor tensile strength. As can be seen in Figure 13, there is a large difference in the amplitude graphs between the different samples. In addition, if TOF is used instead of amplitude for the y-axis, as in Figure 13 it is observed that there is a difference in the two samples as well as seen in Figure 14. Sample B1 (in Figure 14 shows a pattern with blocks of pixels arranged in a 45 degree angle and being much more separated in comparison to sample B2 in which the pixels are arranged in a more horizontal direction and are grouped closer together. If one looks at the cluster analysis data in Table III, sample B2 is zero for both amplitude regions. However, as can be seen in Table IV, there is a difference in the Tensile strength, modulus and Tear strength for the mechanical properties. Figure 14 supports the difference seen in the mechanical property data in Table IV because of the pixel grouping of sample B2 is tighter than those seen in sample B1.

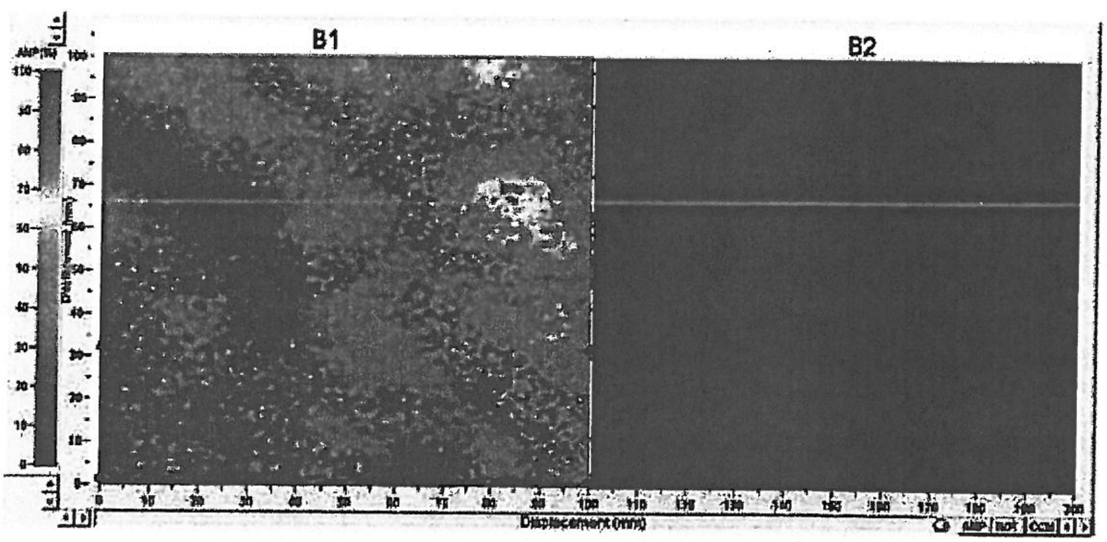

Figure 13. Amplitude C-scan images of different crust leather samples with vertical fiber defect.

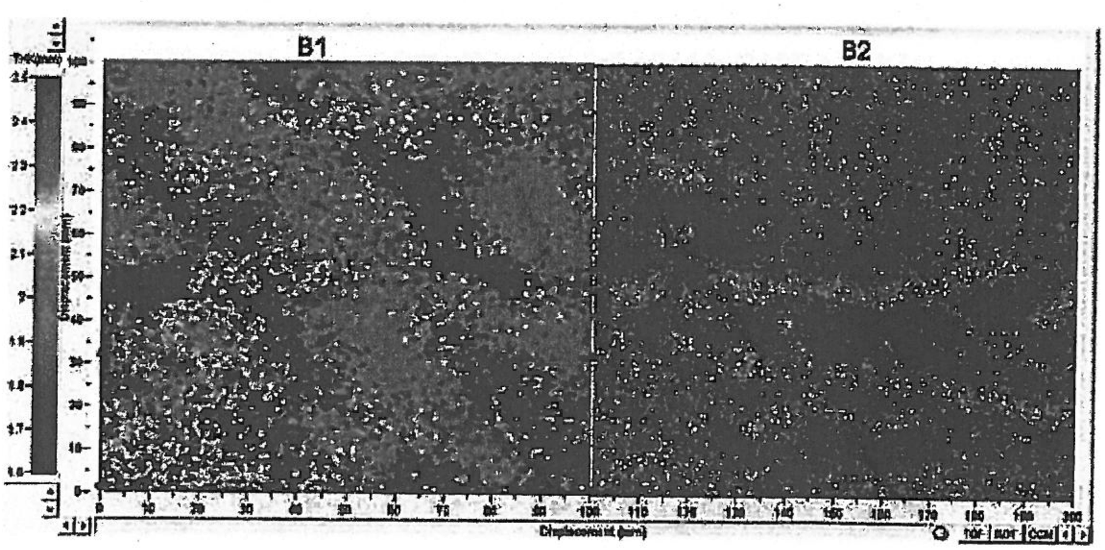

Figure 14 Time of Flight C-scan images of different crust leather samples with vertical fiber defect.

TABLE III
Vertical Fiber versus percent area amplitudes.

Figure 11 vertical fiber	Percent Area between 80-100% AMP	# Clusters	Percent Area between 20-50% AMP	# Clusters
B1	0.02	1	77.94	1
B2	0	0	0	0

TABLE IV
Mechanical properties of Vertical Fiber samples.

	Tensile Strength	Elongation	Modulus	Toughness	Tear Strength Normalized
	MPa	%	MPa	J/cm^3	N/mm
B1	1.26 ± 0.04	47.84 ± 1.95	4.11 ± 0.36	0.34 ± 0.01	3.08 ± 0.39
B2	1.64 ± 0.13	49.46 ± 3.50	3.39 ± 0.41	0.41 ± 0.06	4.16 ± 0.41

CONCLUSIONS

This study focused on the development of an airborne ultrasonic technology to evaluate the quality of hides and leather. The key for success in AU testing is to use AU transducers with low resonant frequencies, which leads an effective transmission of ultrasound waves through hides or leather. There are still many difficulties that have to be overcome to lead this technology to be mature enough to be commercially applied to the hides and leather industries. The moisture content of the test sample is an important factor affecting scanning results besides the sample's thickness and elasticity. The detection of defects will be significantly affected by the above-mentioned factors. There are many graphic presentations that can be used in the testing, among them, it appears that time of flight may provide some interesting images that reveal more information about defects such as vertical fibers. It was also demosnstrated that the moisture content of shaved wet blue is favorable for good C-scans.

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